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MEMORANDUM FOR: Mr. Russ Forba, USEPA Region 8 Montana Office

FROM: Paul R. Schroeder, PhD, PE, Research Civil Engineer

SUBJECT: Estimation of Contaminant Release from Dredging of Clark Fork and Blackfoot River Sediments in Milltown Reservoir

1. Introduction: The USEPA Region 8 Montana Office has requested the U.S. Army Corps of Engineers to generate predictions of the range of changes in water quality in the Clark Fork River at Missoula, MT, during dredging of contaminated sediments in Milltown Reservoir at Milltown, MT. Milltown Reservoir is a Superfund site contaminated by metals from mining and smelting activities on the Upper Clark Fork River. The principal contaminants of concern are arsenic, cadmium, copper, lead and zinc. Milltown Dam and Reservoir are located at the confluence of the Blackfoot and Clark Fork Rivers about 5 miles upstream from Missoula, MT. A number of remediation alternatives exist, and they generally include dredging or excavating at least 1 million cubic yards of sediment by one or more hydraulic or mechanical dredges or conventional excavation equipment over a five-month construction period from July through November in one or more years.

2. Key Factors Affecting Water Quality During Dredging: The range of effects of dredging on total suspended solids (TSS), arsenic, cadmium, copper, lead and zinc concentrations is likely to be quite broad due to variability in the chemical and physical characteristics of sediments as well as variability in the dredging losses, dredging production rates, effectiveness of best management practices (BMPs), flow rates, water depths, and water velocities. BMPs for dredging consist primarily of the proper selection of dredge type and model, control of the dredge operation to control release of resuspended material. Sediments will vary in their contaminant concentrations, contaminant distribution between liquid and solid phases, dry bulk density, and grain-size distributions. Higher contaminant concentrations and higher fine-grained sediment concentrations will increase the losses of contaminants to the water column. Dredging losses expressed as a fraction of the volume or dry mass of the sediment vary based on operation of the dredge and operating conditions. For example, hydraulic dredges tend to lose more material at the end of their swings, when cutting upward through the material (moving left with a clockwise turning cutterhead) rather than cutting downward (moving right with a clockwise turning cutterhead) and when making partial cuts in depth rather than full cuts. Higher dredging losses will increase the losses of contaminants to the water column. Dredging production rates vary with the number, movement, maintenance, and size of dredges. Higher production rates increase the rate of contaminant losses to the water column. Flow rates are variable with season, snow accumulations, groundwater levels, and current weather. Low flow rates reduce the dilution of the contaminant losses. Therefore, a wide range of changes in water quality is likely to result from dredging, and predictions of the effects must include the likely variability of the system. Analysis of impacts on water quality should incorporate known or estimated probability distributions for key factors; a common procedure for doing so is Monte Carlo analysis.

3. Objectives: The objectives of this analysis are:

a. Determine the variability in the principal parameters affecting water quality during dredging. Quantify the probability distribution function for the principal parameters by estimating their values at the 5th, 15th, 25th, 35th, 45th, 55th, 65th, 75th, 85th and 95th percentiles.

b. Predict the probability distribution function for the increase in total concentration of suspended solids, arsenic, cadmium, copper, lead and zinc in the Clark Fork River at Missoula, MT, during cutterhead hydraulic dredging of the Milltown Reservoir sediments without implementation of BMPs using a Monte Carlo approach. (It is assumed that mechanical dredging or excavation of sediments would be performed in the dry and, therefore, would not affect the water quality. The analysis does not account for any resuspension resulting from mechanical removal of debris.)

c. Estimate the probability distribution function for the increase in dissolved concentration of arsenic, cadmium, copper, lead and zinc in the Clark Fork River at Missoula, MT, during cutterhead hydraulic dredging of Milltown Reservoir sediments based on predictions of total contaminant concentrations and the distribution of contaminants between the liquid and solid phases in the water column and in the pore water.

4. Sediment Contaminant Concentrations: Site-specific total contaminant concentrations in the sediment were compiled from references a-d. (References are in paragraph 23.) A database of contaminant concentrations was tabulated and sorted in ascending order, containing 291 values for arsenic, 233 values for cadmium, 291 values for copper, 232 values for lead, and 290 values for zinc. The distributions of the sorted values are presented in Table 1. The sediment contaminant concentrations appear to be log normally distributed.

5. Dredging Losses: Dredging loss estimates expressed as a fraction of the dry weight or volume of the in situ sediment were obtained from the Hayes and Wu (2001) paper entitled "Simple Approach to TSS Source Strength Estimates" (Western Dredging Association [WEDA] Proceedings, WEDA XXI, Houston, TX, June 25-27, 2001). The data consist of 294 estimates of losses from two 12-inch cutterhead dredges (12 estimates from one site and 282 estimates from another site); additionally, the database has 43 estimates of losses from 18-inch cutterhead dredges collected at two sites and 51 estimates of losses from a 10-inch cutterhead dredge at one site. The dredging loss was computed by measuring the TSS concentration and velocity in a vertical cross-section of the plume downstream from the dredge but in close proximity. These field data were used to compute mass loss rate which was divided by dredging mass production rate (volumetric production rate times the dry bulk density of the in situ sediment) to compute the dredging loss fraction. All estimates of dredging losses were made in the absence of best management practices. The data for the 12-inch dredges were used to estimate the distribution of losses for this analysis. The data for the other cutterhead dredges were similar in distribution although the average and maximum loss fractions were smaller. Therefore, data for the 12-inch cutterhead dredge are more conservative (predicts higher losses). The dredging loss data were sorted in ascending order and its distribution is shown below in Table 2. Sediment resuspension data for horizontal auger dredges (Mudcat dredge) and mechanical dredges (open and closed clamshells) are significantly (at least 3 times) higher than for the cutterhead dredges used in

TABLE 1. DISTRIBUTIONS OF SEDIMENT CONTAMINANT CONCENTRATIONS

Percentile	Sediment Contaminant Concentration (mg/kg)				
	Arsenic	Cadmium	Copper	Lead	Zinc
5	7	0.96	36	16	56
15	22	2.56	145	37	424
25	37	3.60	223	56	685
35	56	4.40	397	89	880
45	80	5.20	569	108	1161
55	123	6.00	826	135	1526
65	168	9.44	1305	182	2298
75	268	12.00	2050	277	3285
85	460	19.00	3130	420	4617
95	815	27.00	5550	630	7824
Mean	240	9.60	1504	200	2294
Minimum	1	0.51	10	4	21
Maximum	7889	53.00	10800	900	11200

this analysis (Hayes and Wu, 2001; Cullinane et al., 1986, "Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material," Puget Sound Dredged Disposal Analysis).

6. Stream Flow: Daily mean stream discharge data (4743 values) from USGS Station Number 12340500 at Clark Fork River above Missoula, MT, and below Milltown Dam for the months of July through November in years 1969 through 1999 were compiled and sorted in ascending order. Fifty data points exceeding 7500 cfs (all in early July from 7 of the 31 years of data) were excluded from the data set. Flows below 7500 cfs are expected to yield near bank velocities below 1.5 fps; these velocities are consistent with use of Best Management Practices such as silt curtains (see paragraph 21). Exclusion from the data set is based on the reasonable assumption that this flow rate would be the upper limit for cutterhead dredging in a given year. The distribution of the stream flow data is shown in Table 2.

7. Dredging Production Rates: Three dredging production rates were selected to occur with equal likelihood. The production rates were selected to meet the overall project requirements of a million cubic yards in a 5-month period of time. It is assumed that the dredge or dredges could be 12-, 14- or 16-inch cutterhead dredges. It is further assumed that one or two dredges could be used for all or part of the dredging period. The three production rates while operating are 140, 210, and 280 cubic meters per hour. Many other dredging alternatives could be examined, but the variability in the production rate is captured by this range.

TABLE 2. DISTRIBUTIONS OF DREDGING RESUSPENSION FRACTIONS AND STREAM FLOW RATES

Percentile	Dredging Resuspension Fraction of Dry Mass or Volume (w/w) or (v/v)	Flow Rate in Clark Fork River at Missoula, MT (cfs)
5	0.00007	854
15	0.00018	1130
25	0.00029	1310
35	0.00041	1450
45	0.00060	1580
55	0.00098	1710
65	0.00134	1850
75	0.00154	2000
85	0.00183	2470
95	0.00272	4100
Mean	0.000944	1881
Minimum	0.000005	558
Maximum	0.003840	7460

8. Sediment Dry Bulk Density: An average dry bulk density was computed for the sediments. Moisture content data were available for only 58 of the 292 sediment samples cited in paragraph 4. To compute dry bulk density from moisture content data, it was necessary to estimate the specific gravity of the sediment particles. Specific gravity was measured for 48 samples. The average specific gravity was 2.53; the specific gravity ranged from 2.45 to 2.70. The average dry bulk density was 1343 kg/cubic meter; the dry bulk densities ranged from 811 to 1705 kg/cubic meter.

9. Total Contaminant Concentration Calculations: The increase in the total suspended solids concentration from dredging in the absence of BMPs is equal to:

$$\Delta\text{TSS} = \text{Dry Bulk Density} \times \text{Production Rate} \times \text{Dredging Loss Fraction} / \text{Flow Rate}$$

The increase in the water column total contaminant concentration from dredging in the absence of BMPs is equal to:

$$\Delta\text{Total Concentration} = \text{Sediment Contaminant Concentration} \times \Delta\text{TSS}$$

A Monte Carlo analysis was performed using the above equations to determine the distribution of the increase in total contaminant concentrations in the water column below the Milltown Dam at Missoula, MT. In the analysis, each of the 3 production rates was used with each of the 10 dredging loss factors and 10 flow rates to generate a collection of 300 ΔTSS concentrations that have equal likelihood of occurrence in the absence of BMPs. These 300 ΔTSS values were used with the 10 sediment contaminant concentrations for each of the 5 contaminants to generate 3000 ΔTotal Concentration values for each of the 5 contaminants.

10. Total Contaminant Concentration Results: The ΔTSS and ΔTotal Concentration in the absence of BMPs were sorted and their distributions are presented in Table 3. The increase in total concentration (including both acid soluble and insoluble arsenic and metals fractions from suspended particulates) are predicted by the method used in this paper because the sediment contaminant concentrations available for use in this analysis were reported as total concentrations and not total recoverable concentrations. The increases in total concentrations reported in this paper will be somewhat higher than the increases in total recoverable concentrations (containing only the acid soluble portions of the suspended particulates) that are measured in the water column and form the basis for the Montana Circular WQB-7 Standards. Therefore, the ΔTotal Concentration approach is considered to be a conservative overestimate for the increase in Total Recoverable Metals. The ΔTSS and ΔTotal Concentration results appear to be log normally distributed.

11. Comparison of Potential Increases in Total Contaminant Concentration with Montana Numerical Water Quality Standards for Surface Water: The Montana Circular WQB-7 Standards for acute and chronic toxicity to aquatic life were compared with the predicted increases in total contaminant concentration (a conservative substitute for total recoverable contaminant concentration) in the absence of BMPs. These comparisons are summarized below. The predicted increases in total concentrations of arsenic, cadmium and zinc are well below the acute and chronic toxicity standards. The predicted increases in the concentrations of lead are well below the acute toxicity standard but are estimated to exceed the chronic toxicity standard less than 1 percent of the time and only for short durations. The predicted increases in the concentrations of copper are estimated to exceed the acute toxicity standard about 3 percent of the time and to exceed the chronic toxicity standard about 5 percent of the time. The predicted increases in total concentrations of arsenic are also well below the Montana drinking water standard.

12. Ambient Water Quality: Dissolved and total recoverable contaminant concentrations in the ambient water column were compiled from the USGS Surface Water Quality database for USGS Station 12340500 on the Clark Fork River at Missoula, MT; approximately 33 samples collected between June 1990 and December 1999 during the months of July through November were analyzed in this evaluation. The distributions of total recoverable and dissolved contaminant concentrations in the ambient water are given in Tables 4 and 5.

13. Impact of Ambient Conditions on Exceedances of Total Recoverable Contaminant Concentrations During Dredging Without BMPs: Evaluation of Tables 3 and 4 shows that the predicted total recoverable concentrations of arsenic and zinc would be well below the acute and chronic toxicity standards during the dredging period, even without utilization of silt curtains. The predicted total recoverable concentration of cadmium would also be below the acute and chronic toxicity standards, but there is about a 2 percent probability that the chronic standard could be exceeded for short periods of time. However, this is because the ambient concentration nearly equals the chronic toxicity standard about 75 percent of the time. The predicted total recoverable concentration of lead would be well below the acute toxicity standard; however, the predicted total recoverable concentration of lead would exceed the chronic toxicity standard about 16 percent of the time (about 1 percent more frequently than

TABLE 3. PREDICTED DISTRIBUTIONS OF INCREASES IN TSS AND TOTAL CONTAMINANT CONCENTRATIONS

Percentile	ΔTotal Contaminant Concentration (ug/L) in the Water Column					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	31	0.0004	0.00005	0.0019	0.0008	0.0029
0.5	47	0.0007	0.00010	0.0038	0.0017	0.0059
1	63	0.0011	0.00014	0.0059	0.0024	0.0093
3	82	0.0026	0.00029	0.0146	0.0048	0.0268
5	113	0.0040	0.00042	0.0233	0.0072	0.0478
10	171	0.0081	0.00076	0.0492	0.0137	0.1056
20	337	0.0192	0.00161	0.1206	0.0296	0.2617
30	549	0.0355	0.00275	0.2392	0.0511	0.5239
50	1152	0.1012	0.00662	0.7028	0.1266	1.4442
70	2168	0.2628	0.01471	1.8837	0.2981	3.4159
80	2942	0.4640	0.02285	3.3379	0.4852	5.6624
90	4237	0.9748	0.04109	6.8519	0.9103	10.678
95	5439	1.6551	0.06506	11.773	1.4529	17.404
97	5985	2.2933	0.08317	15.701	1.8811	22.726
99	7913	3.5859	0.12652	24.420	2.9051	35.048
99.5	8878	4.7166	0.15859	32.119	3.7005	45.279
99.9	11748	7.1800	0.23788	48.894	5.5502	68.928
Mean	1768	0.3599	0.01594	2.5157	0.3447	4.0227
Minimum	31	0.0002	0.00003	0.0011	0.0005	0.0018
Maximum	11748	9.5743	0.31719	65.199	7.4010	91.913
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18	82	120
Chronic		190**	1.1	12	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).

** WQB-7 Arsenic standard for protection of human health is 20 ug/L.

TABLE 4. DISTRIBUTIONS OF TSS AND TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS IN AMBIENT WATER WITHOUT DREDGING

Percentile	Total Recoverable Contaminant Concentration (ug/L) in Ambient Water					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
5	2000	3.00	0.11	3.06	0.92	10.00
15	3050	3.56	0.34	4.00	1.00	10.00
25	5000	4.00	1.00	4.90	1.00	10.00
35	6000	4.06	1.00	5.00	1.00	10.00
45	6000	4.64	1.00	5.60	1.00	17.10
55	8000	5.00	1.00	6.57	1.00	20.00
65	9000	5.96	1.00	8.00	1.54	30.45
75	14000	6.50	1.00	10.00	2.30	31.00
85	25900	7.11	1.00	19.98	3.11	31.85
95	33300	8.02	1.00	23.16	5.70	40.00
Mean	11690	5.24	0.85	9.33	1.94	21.14
Minimum	2000	3.00	0.11	2.00	0.70	10.00
Maximum	42000	10.00	1.00	24.83	8.59	44.00
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18	82	120
Chronic		190**	1.1	12	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** WQB-7 Arsenic standard for protection of human health is 20 ug/L.

under ambient conditions without dredging). The predicted total recoverable concentration of copper would exceed the acute toxicity standard about 19 percent of the time (about 2 percent more frequently than under ambient conditions without dredging). The predicted total recoverable concentration of copper would exceed the chronic toxicity standard about 30 percent of the time. However, this is primarily because the ambient total recoverable concentration of copper exceeds the chronic toxicity standard more than 25 percent of the time during the period of interest.

14. Distribution (Partitioning) Data: The distribution of contaminants between the liquid and solid phases presently in the water column and in the pore water was examined to estimate the distribution coefficients for the contaminants. The calculated distribution coefficients for

TABLE 5. DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATIONS IN AMBIENT WATER WITHOUT DREDGING

Percentile	Dissolved Contaminant Concentration (ug/L) in Ambient Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
5	2.00	0.10	1.00	0.50	1.06
15	3.00	0.10	1.55	0.50	2.23
25	3.00	0.10	1.87	0.50	3.00
35	3.87	0.10	2.00	0.50	3.00
45	4.00	0.10	2.00	0.50	3.00
55	4.00	0.10	2.58	0.50	3.27
65	4.89	0.10	3.03	0.50	5.00
75	5.25	0.10	4.05	0.58	7.34
85	5.67	1.00	4.72	1.00	11.20
95	6.00	1.00	22.15	1.00	20.50
Mean	4.19	0.26	5.52	0.73	6.44
Minimum	1.00	0.10	1.00	0.50	1.00
Maximum	6.34	1.00	63.00	5.00	28.00

both the Clark Fork River and the pore water were then used to estimate the changes in dissolved contaminant concentrations during dredging in the absence of BMPs. Dissolved concentrations provide the most accurate indications of potential environmental impacts. Distribution coefficients (K_d) for all five contaminants of concern were computed for 37 sediment samples that had measurements of pore water and total contaminant concentrations presented in the Draft Remedial Investigation Report for ARCO (Titan Environmental Corporation 1995). The 37 estimates of K_d for each contaminant were sorted, and the median values were selected as the representative distribution coefficients for the in situ sediment. The median values were somewhat lower than the mean values and, therefore, more conservative. The distribution coefficients for the contaminants would be expected to be different in the water column than in the in situ sediments due to differences in pH and oxidation conditions. As such, distribution coefficients were also computed for the ambient water in the Clark Fork River at Milltown Reservoir and at Missoula, MT. Dissolved and total recoverable contaminant concentrations in the water column were compiled from the USGS Surface Water Quality database for USGS Station 12340500 on the Clark Fork River at Missoula, MT; approximately 33 samples collected between June 1990 and December 1999 were analyzed in this evaluation. The distribution coefficients for the 33 samples were sorted, and the median values were selected as the representative distribution coefficients for the water column. The median values were somewhat lower than the mean values and, therefore, more conservative. The results of the distribution evaluation are summarized in Table 6.

TABLE 6. SUMMARY OF DISTRIBUTION COEFFICIENTS

Location	Distribution Coefficient, L/kg				
	Arsenic	Cadmium	Copper	Lead	Zinc
In Situ Sediment	237	1280	41300	35200	2960
Water Column	10100	34600	83000	50000	77800

15. Δ Dissolved Contaminant Concentration Calculations: The increase in the water column dissolved contaminant concentration from dredging without BMPs is equal to:

$$\Delta \text{ Dissolved Concentration} = \Delta\text{Total Concentration} / [1 + (K_d \times \Delta\text{TSS})]$$

Δ Dissolved Concentrations were computed for the 3000 ΔTotal Concentrations estimates for each contaminant using the corresponding ΔTSS value for the ΔTotal Concentration estimates and both distribution coefficients.

16. Predictions of Δ Dissolved Contaminant Concentrations: The Δ Dissolved Concentration results for each contaminant were sorted and their distributions are presented in Table 7 for the case employing the in situ sediment distribution coefficients. The in situ sediment distribution coefficients were lower than the water column distribution coefficients. The lower distribution coefficient yields the higher prediction of dissolved concentration. The differences in the predictions for the two distribution conditions varied by contaminant (less than 10 percent and often less than 2 percent for arsenic and lead, less than 20 percent and often less than 5 percent for cadmium and copper, less than 40 percent and often less than 10 percent for zinc), but greater at the larger concentrations. The results appear to be log normally distributed. Actual increases in dissolved concentrations may be somewhat smaller because the ambient TSS concentrations are much larger than the increases in TSS from dredging. As such, some of the predicted dissolved contaminants may partition to the ambient TSS or iron oxides formed from the dredging releases. The difference between total recoverable contaminant concentration and dissolved concentration increases greatly with increases in TSS. On average in the ambient water, the dissolved concentrations of contaminants were about 50 percent of the total recoverable concentrations of contaminants while on average in dredging losses the predicted increases in dissolved concentrations were about 95 percent of the total concentrations.

17. Comparison of Increase in Dissolved Contaminant Concentration with Water Quality Criteria Without BMPs: The predicted increases in dissolved concentrations of arsenic, cadmium and zinc are well below the acute and chronic toxicity standard and Federal criteria. The predicted increases in the concentrations of lead are well below the acute toxicity criterion but are estimated to exceed the chronic toxicity standard and Federal criterion about 1 percent of the time for short durations. The predicted increases in the concentrations of copper are estimated to exceed the acute toxicity standard and Federal criterion about 3 percent of the time and to exceed the chronic toxicity standard and Federal criterion about 6 percent of the time without BMPs.

TABLE 7. PREDICTED DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATION INCREASES

Percentile	Δ Dissolved Contaminant Concentration (ug/L) in the Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	0.0004	0.00005	0.0023	0.0008	0.0029
0.5	0.0007	0.00010	0.0041	0.0017	0.0059
1	0.0011	0.00014	0.0059	0.0024	0.0093
3	0.0026	0.00029	0.0145	0.0048	0.0268
5	0.0040	0.00042	0.0232	0.0071	0.0478
10	0.0081	0.00076	0.0480	0.0134	0.1051
20	0.0191	0.00161	0.1158	0.0290	0.2616
30	0.0354	0.00275	0.2307	0.0492	0.5229
50	0.1011	0.00660	0.6534	0.1204	1.4397
70	0.2626	0.01466	1.7369	0.2762	3.3915
80	0.4636	0.02274	3.0176	0.4443	5.6353
90	0.9745	0.04074	6.1437	0.8207	10.5626
95	1.6543	0.06463	10.2103	1.2792	17.2073
97	2.2906	0.08264	13.3539	1.6704	22.4473
99	2.5822	0.12545	20.4098	2.4185	34.5720
99.5	4.7101	0.15741	25.7658	3.0289	44.5165
99.9	7.1650	0.23522	35.8531	4.2364	67.1761
Mean	0.3596	0.40000	2.2036	0.3073	3.9801
Minimum	0.0002	0.00003	0.0011	0.0005	0.0018
Maximum	9.5477	0.31249	43.9000	5.2359	88.8246
Federal Freshwater Water Quality Criteria for Protection of Aquatic Life*					
Acute	340*	4.3**	13**	65**	120**
Chronic	150*	2.2**	9**	2.5**	120**

* WQB-7 Arsenic standard for protection of human health is 20 ug/L.
** Assumes a 100 mg/L hardness; criterion is based on actual hardness measured at time of sampling.

18. Impact of Ambient Conditions on Exceedances of Dissolved Contaminant Concentrations During Dredging Without BMPs: Integration of Tables 5 and 7 shows that the dissolved concentrations of arsenic, cadmium and zinc are predicted to be well below the chronic toxicity and Federal criteria throughout the dredging without BMPs. The dissolved arsenic concentration in the water column is predicted to be below the Montana WQB-7 Standard for protection of human health. The dissolved concentration of lead is predicted to be well below the acute toxicity criterion; however, the dissolved concentration of lead is expected to exceed the chronic toxicity standard and Federal criterion about 3 percent of the time. The dissolved concentration of copper is expected to exceed the acute toxicity standard and Federal criterion about 10 percent of the time. The dissolved concentration of copper is expected to exceed the chronic toxicity standard and Federal criterion about 15 percent of the time. This is because the ambient dissolved concentration of copper exceeds the acute toxicity standard and Federal criterion about 10 percent of the time and exceeds the chronic toxicity standard and Federal criterion more than 12 percent of the time.

19. Extreme Events: The extreme events (>90% and <10%) predicted in this analysis are not likely to be seen at Missoula. Dredging losses are highly variable in short periods of time; therefore, longitudinal dispersion will decrease the magnitude of the extreme events with distance from the source. In addition, the contaminant concentrations in the sediment are highly variable spatially and with depth. As such, the loss of highly contaminated sediments is likely to occur for short periods of time. The duration of high dredging losses or exposure of high contamination may be on the order of minutes while the time available for longitudinal dispersion may be an hour or more.

20. Best Management Practices: BMPs for dredging consists primarily of proper selection of dredge type and model, control of the dredge operation to minimize resuspension, and the use of silt curtains around the dredging site to control release of resuspended materials. Cutterhead hydraulic dredges, when well operated, produce among the lowest resuspension of common dredge types. Control of cut depth, swing speed, cutterhead rotational velocity, and flow rate can reduce resuspension. Silt curtains, when used in the right setting have been shown to be very effective in controlling the loss of resuspended materials (Fort James Corporation et al. 2001 and Averett et al. 1996. For example, no statistically significant increase in suspended solids concentrations was measured outside of the silt curtains at Fox River and Buffalo River. Silt curtains are not recommended for use in areas with velocities greater than 1.5 fps or in areas with significant tidal fluctuations (Otis 1994 and Johanson 1976, 1977 and 1978). To be effective silt curtains should not block a large fraction of the cross-sectional area of the flow and should be arranged to direct the flow around the area to be enclosed.

21. Application of Silt Curtains at Milltown Dredging Site: During the dredging the flow in the Clark Fork River above the Milltown Dam will average about 900 cfs with a maximum flow of about 4000 cfs. The typical cross-section of the Clark Fork River in the Milltown Reservoir in the vicinity of proposed dredging is about 2500 sq ft in area. Therefore, typical velocities would range from 0.2 to 0.6 fps. Velocities exceeding 1.0 fps should occur on average only about 4 days per dredging season (July - November), and velocities during dredging are not predicted to exceed 1.5 fps (see paragraph 6). Due to the low velocity regime during the assumed dredging period, silt curtains should be highly effective so long as the area of blockage is kept below 25 percent of the cross-sectional area of flow. Significant increases in resuspension for short periods of time may be expected when the silt curtains are repositioned from one dredging location to the next.

22. Estimates of Increase in Water Column Contaminant Concentrations During Dredging with BMPs: When effective, no increase in suspended solids concentrations can be measured outside of the silt curtains. Data on the effectiveness of silt curtains for controlling release of dissolved contaminants are not available in the literature. Reduction of dissolved contaminant losses would be a function of the reduction of the flow in the vicinity of the dredge by the silt curtain. Flow is equal to cross-sectional area times velocity. Therefore, to estimate the fraction of the stream flow passing through the enclosed area, it is necessary to estimate the fraction of the cross-sectional area of flow enclosed by the silt curtain and the reduction of velocity through the enclosed area. Next, it is necessary to estimate the dissolved concentration of contaminants within the silt curtain assuming equilibrium with the estimated total suspended solids inside the silt curtain. Finally, the dissolved concentration within the silt curtain must be mixed with the ambient water column total recoverable contaminant concentration in proportion to the flow of each to estimate the total recoverable contaminant concentration during dredging with BMPs. Three sets of example estimates of the total recoverable contaminant concentrations during dredging with BMPs for a single dredge are given in Table 8 using average sediment total contaminant concentrations and average ambient water column total recoverable contaminant concentrations with equal flow from the Blackfoot and Clark Fork Rivers. Each set of estimates gives the predicted total recoverable contaminant concentrations for a range of velocity or flow reductions through the area enclosed by silt curtains. Each set represents a different configuration or size of area enclosed by the silt curtains: 50%, 25% or 10% of the cross-sectional area of either the Clark Fork River or Blackfoot River. Larger areas or volumes of enclosures would tend to produce a lower steady-state concentrations of TSS, which are estimated to vary from 200 mg/L to 500 mg/L for the three example configurations.

23. Conclusions: Arsenic, cadmium, and zinc concentrations are not predicted to exceed the Montana acute toxicity standards during dredging with or without implementation of BMPs. Similarly, arsenic, cadmium, and zinc concentrations are not predicted to exceed the Montana chronic toxicity standards during dredging with or without BMPs. Arsenic concentrations are also not predicted to exceed the Montana WQB-7 Standard for protection of human health during dredging with or without BMPs. Copper concentrations are the only concentrations in this analysis that are predicted to exceed Montana water quality standards for acute toxicity to aquatic life. Copper concentrations in the ambient water column are predicted to exceed Montana water quality standards for acute toxicity to aquatic life about 17 percent of the time without dredging, and about 19 percent of the time with dredging without BMPs. Under average conditions, copper concentrations in the ambient water column are not predicted to exceed Montana water quality standards for acute toxicity to aquatic life during dredging with BMPs. Copper and lead concentrations are the only concentrations in this analysis that are predicted to exceed Montana water quality standards for chronic toxicity to aquatic life. Copper concentrations in the ambient water column are predicted to exceed Montana water quality standards for chronic toxicity to aquatic life about 25 percent of the time without dredging, about 30 percent of the time with dredging without BMPs. Lead concentrations in the ambient water column are predicted to exceed Montana water quality standards for chronic toxicity to aquatic life about 15 percent of the time without dredging, and about 16 percent of the time with dredging without BMPs. Under average conditions, copper and lead concentrations are not predicted to exceed Montana water quality standards for chronic toxicity to aquatic life during dredging with BMPs. The exceedances based on dissolved concentrations of the contaminants are predicted to be infrequent. For these two contaminants, exceedances occur in the ambient water without dredging. Dredging without BMPs is predicted to increase the frequency of exceedances in lead concentration by about

TABLE 8. EXAMPLE ESTIMATES OF TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS DURING DREDGING WITH BMPS

Velocity Fraction	Average TR Concentrations During Dredging w/BMPs				
	As	Cd	Cu	Pb	Zn
Area Fraction = 0.5, TSS Concentration = 200 mg/L					
1	15.36	1.02	15.12	2.70	87.91
0.75	13.34	0.99	13.96	2.55	74.56
0.5	11.02	0.95	12.64	2.38	59.29
0.25	8.35	0.90	11.11	2.17	41.68
0.1	6.55	0.87	10.08	2.04	29.76
0.05	5.90	0.86	9.71	1.99	25.52
Area Fraction = 0.25, TSS Concentration = 350 mg/L					
1	14.26	1.03	12.42	2.36	67.80
0.75	12.22	0.99	11.72	2.26	57.26
0.5	10.05	0.95	10.98	2.16	46.02
0.25	7.73	0.90	10.18	2.05	34.01
0.1	6.26	0.87	9.68	1.99	26.40
0.05	5.75	0.86	9.51	1.96	23.79
Area Fraction = 0.1, TSS Concentration = 500 mg/L					
1	10.33	0.95	10.60	2.11	43.21
0.75	9.11	0.93	10.30	2.07	37.90
0.5	7.85	0.90	9.98	2.03	32.46
0.25	6.56	0.88	9.66	1.98	26.87
0.1	5.77	0.86	9.46	1.96	23.45
0.05	5.51	0.86	9.40	1.95	22.30
Montana Chronic Standards	190.00	1.10	12.00	3.20	110.00
Avg. Amb. TR Conc. (ug/L)	5.24	0.85	9.33	1.94	21.14

1 percent and the exceedances in copper concentration by about 5 percent. Concentrations of copper and lead may be raised for short durations during times of high production, low flows, and high sediment contamination, when silt curtains are repositioned during changes in dredging location, and when debris is being mechanically removed to facilitate hydraulic dredging operations.

24. References:

a. Titan Environmental Corporation (1995). "Milltown Reservoir Sediments Operable Unit, Draft Remedial Investigation Report, Appendix 5B," prepared for ENSR and ARCO.

b. Woessner et al. (1984). "Final Report, Arsenic Source and Water Supply Remedial Action Study, Milltown, Montana," prepared for the Solid Waste Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana.

c. Harding Lawson Associates (1987). "Volume II - Appendices, Milltown Reservoir Data Report, Supplemental Investigations Conducted Under the Feasibility Study," prepared for the Solid and Hazardous Waste Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana.

d. McCulley, Frick & Gilman, Inc. (1998). "Milltown Reservoir Operable Unit, Draft Sediment and Surface Water Sampling Report in Support of the Focused Feasibility Study," prepared for ARCO.

e. Hayes and Wu (2001). "Simple Approach to TSS Source Strength Estimates," Western Dredging Association Proceedings, WEDA XXI, Houston, TX, June 25-27, 2001.

f. Cullinane et al. (1986). "Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material," Puget Sound Dredged Disposal Analysis).

g. Fort James Corporation, Foth & Van Dyke, and Hart Crowser, Inc. (January 2001). "Final Report, 2000 Sediment Management Unit 56/57 Project, Lower Fox River, Green Bay, Wisconsin," prepared for U.S. Environmental Protection Agency and Wisconsin Department of Natural Resources.

h. Averett, Daniel E., et al. (1996). "Buffalo River Dredging Demonstration." Technical Report EL-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

i. Otis, Mark J. (1994). "New Bedford Harbor, Massachusetts Dredging/Disposal of PCB Contaminated Sediments." *Dredging '94--Proceedings of the Second International Conference on Dredging and Dredged Material Placement, Vol. I.* Lake Buena Vista, FL, 13-16 November 1994. E. Clark McNair, ed., American Society of Civil Engineers, New York, NY, 579-587.

j. Johanson, Edward E. (1977). "Application and Performance of Silt Curtains." U.S. Army Corps of Engineers Information Exchange Bulletin. Vol. D-77-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1-8.

k. JBF Scientific Corporation (Johanson, Edward E.). (1978). "An Analysis of the Functional Capabilities and Performance of Silt Curtain." Technical Report D-78-39, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

l. Johanson, Edward E. (1976). "The Effectiveness of Silt Curtains in Controlling Turbidity." *Proceedings of WODCON VII*.